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Skew angle effect in shingled writing magnetic recording

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In the shingled writing scheme the magnetization distribution at the track edge should be controlled to achieve high track densities. In particular, reducing the erase band width is necessary because of its large noise. The erase band width is determined in the writing process by both the head field gradient and SFD. In shingled writing, we can designate either side of the written track as the remaining side due to the progressive scan. In this work, erase band width reduction was accomplished by optimization of the skew. A track pitch decrease of 7% was measured due to skew angle control alone. Additionally, the track pitch improvement due to narrower erase bands was increased from 11 to 21% by narrowing the magnetic read width from 80 to 20 nm.

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1. Introduction

For next-generation high density recording, shingled writing is an interesting approach of magnetic recording with regular granular media [1-4], using a large head pole to write narrow tracks. This writing scheme has the advantage of strong writing field due to the large head pole size. A thermally stable medium can be used with this strong head field.

Shingled writing scheme is realized with unidirectional and progressive head seek motion. A written track is partly overwritten by the following writing. Limiting factors to achieve a minimum track pitch in shingled writing will be different from those in conventional writing. Therefore, one of the important issues for shingled writing is to clarify what determines track density.

In conventional writing, 747 curve performance which is the dependence of off-track capacity on squeezed track pitch is usually carried out and the track pitch for demonstration is obtained. We have already estimated the track pitch of shingled writing in comparison to conventional writing. In the study, two squeeze methods according to the positions of the data and adjacent tracks were assumed: double squeeze and single squeeze. In double squeeze, the

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central data track is squeezed by adjacent tracks on both sides. On the other hand, in single squeeze, the data track is squeezed by an adjacent track on one side only. Shingled writing is always in the condition of single squeeze. In the case of single squeeze, the relationship between off-track capability and squeezed track pitch was also derived analytically. The slope of 747 curve of single squeeze became gentler than that of double squeeze. Accordingly, higher track density was accomplished in the case of shingle squeeze assuming the existing head and media.

In the conventional scheme, narrow magnetic write width (MWW) and reduction of noisy erase band widths (EBW) at both track edges are required. On the other hand, we can designate either side of written track as a remained side due to the progressive scan in shingled writing. If the reduction of erase band at either side is possible, it will be an advantage for shingled writing in higher track density.

In this study, we focused on the reduction of erase band width. The reduction using the existing head was carried out by skewing the head. Erase band widths for various skew angles were accurately measured by experiment. The achievable track pitch was estimated from 747 curves also in the future narrow reading case.

2. Experimental setup and measurement of erase band widths

A wrap-around-shield head was used as a writer and a TMR head as a reader was used. The physical track widths of the writer and reader were 180 and about 80 nm in nominal, respectively. A commercial disk was employed for these experiments. Error rate performances were measured using a hardware tester, Marvell 5575. The erase band width was measured by an accurate method using the derivative function of the two off-track profiles [5, 6]. The accurate method for erase band width was based on the accurate measurement method for magnetic write width using the derivative function of off-track profile [7]. Magnetic read width (MRW) of 80 nm was confirmed using micro-track profile method.

Fig. 1 shows the dependence of the erase band width on recording density for skew angles of +5, 0, -5, and -10 degrees. Negative skew angles significantly suppressed the erase band width. The erase band width of the skewed writing was about 30% less than for regular recording with 0 deg. skew. The reduction of erase band width indicated that the head field gradient along cross-track direction which projected the switching field distribution of the magnetic grains or magnetic clusters to the irregularity of magnetization distribution was changed by skew angle.

Schematics of written tracks (left) and main-pole to shield distances for negative, 0, and positive skew angles are depicted in Fig. 2. When a trapezoidal write pole was skewed by -10 degrees, erase bands were written by the sharply-angled corner of the pole, and the erase band width was smallest. This is because the distance from the main pole to the trailing shield was smaller than to the side shield. The SEM image of shield structure in the published paper [8] show the gap to side shield has several times wider than the gap to trailing shield. Consequently, the head

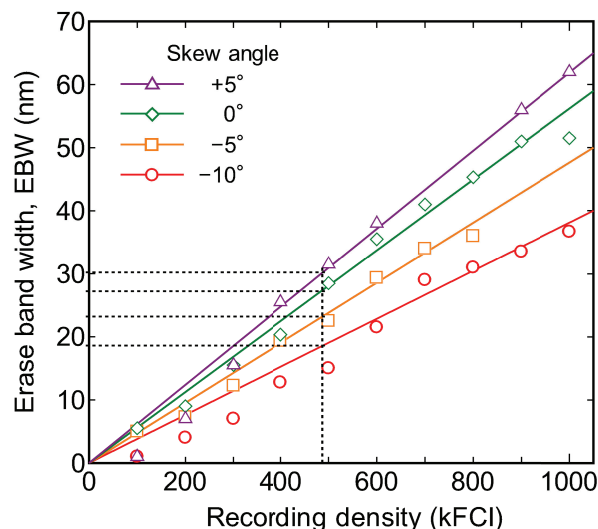


Fig. 1 Dependence of erase band width on linear recording density for several skew angles.

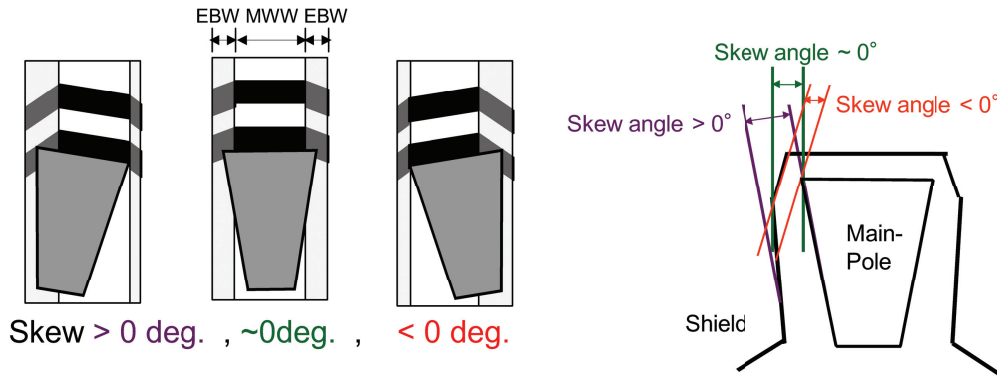


Fig. 2 Schematics of written tracks (left) and main-pole to shield distances for negative, 0, and positive skew angles.

field gradient along down-track direction is expected to be shaper than that along cross-track direction. Negative skew contributed to writing erase bands with a steeper head field gradient along down-track direction. These results indicates the sum of the erase band widths on either side of the head was almost constant for several skew angles, but it is possible to control the width of the erase band on one side.

3. 747 performance for various skew angles

The effect of the reduced erase band width on the 747 curve was investigated. In our previous study, we modeled 747 curves in two cases: double squeeze and single squeeze [2]. Wider OTC will be ensured by reducing the erase band width. The analysis formula of 747 curves for single squeeze in [2] was used for this investigation.

Fig. 3 shows the four measured 747 curves for skew angles of +5, 0, -5, and -10 degrees during recording. Head was also skewed during reproducing. Although the experimental points were scattered, the 747 curve was gradually improved by skewing the head to -10 degrees. In the figure, four analytical relationships between off-track capability and squeezed track pitch in the case of single squeeze expressed below were drawn.

$$OTC_{\text{Single-Sq.}} = \frac{TP}{2} - \frac{EBW}{2} - \frac{1}{2} \frac{S-N}{S+N} MRW \quad (1)$$

where OTC, TP, EBW, MRW are off-track capability, squeezed track pitch, erase band width, magnetic read width, respectively. S and N are read track widths of signal component in read head and one of noise components. These widths are shown in Fig. 4. Eq. (1) can be derived easily from the two equations (2), (3) by using residual data width, RDW.

$$RDW = TP - EBW \quad (2)$$

$$OTC_{\text{Single-Sq.}} = \frac{RDW}{2} - \frac{1}{2} \frac{S-N}{S+N} MRW \quad (3)$$

The analytical slopes drawn in the figure were the cases of EBW of 30, 27, 23, and 19 nm, which were measured for skew angles of +5, 0, -5, and -10 degrees. These lines had good agreement with the measured curves. The achievable linear density defined as the density with the byte error rate of 10^{-4} was also measured. In Fig. 5, the dependence of byte error rate on linear density for several skew angles is plotted. In these cases, the linear densities were almost the same for each skew angle. Therefore, achievable areal density depended almost on the achievable track density. The achievable track pitch is defined as the point where the 15% line of TP and the 747 curve intersect. From the analytical calculation, a track pitch reduction of 11% was estimated, and 7% of this was accomplished in

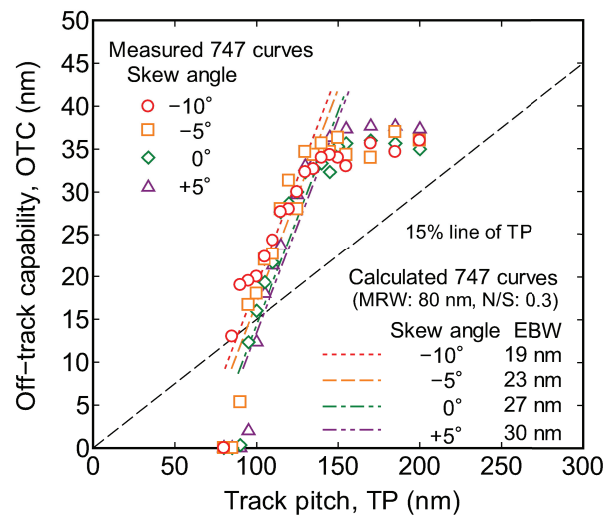


Fig. 3 747 curves for several skew angles. Experimental data were marked and each data was fitted with analytical lines.

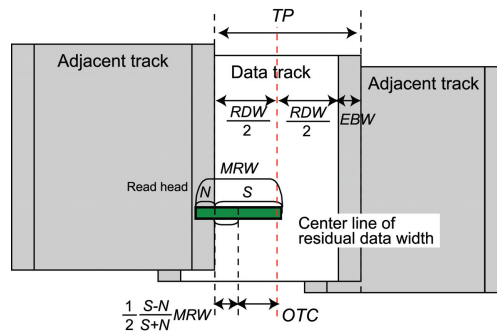


Fig. 4 Relationship between magnetic read width and off-track capability in single squeeze condition.

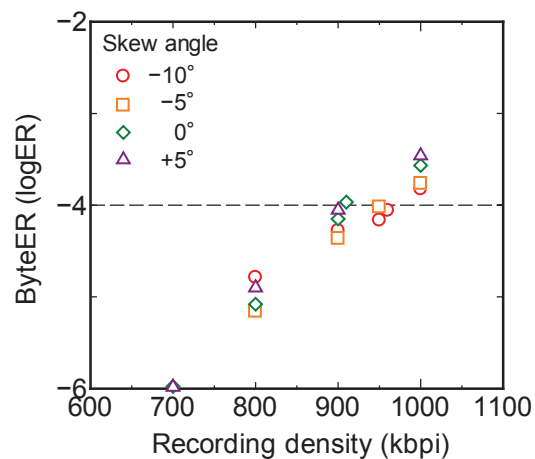


Fig. 5 Dependence of byte error rate on linear recording density for several skew angles. The criterion for estimating achieved linear density was the byte error rate of 10^{-4} .

these measurements through skew angle control. The reduced erase band width on one side is suitable for shingled writing and also shows the potential of narrower erase bands written by an optimized 'corner head'.

4. Narrow track pitch using narrow reader

The possibility of narrow track pitch using narrow reader was estimated using analytical 747 curves. In Fig. 6, Analytical 747 curves in the cases of MRW of 80, 40, and 20 nm. Skewed case was also plotted in the figure. In this estimation, skewing both writer and reader was assumed. The diagonal lines move upward when EBW is decreased and MRW is decreased, because the intercept terms include both EBW and MRW in (1). Finally, achieved track pitch versus magnetic read width is shown in Fig. 7. By decreasing MRW, achieved track pitch was decreased proportionally. However the difference between 0 skew and skewed condition was almost constant, the improvement effect of track pitch was increased from 11 to 21% by narrowing the magnetic read width from 80 to 20 nm.

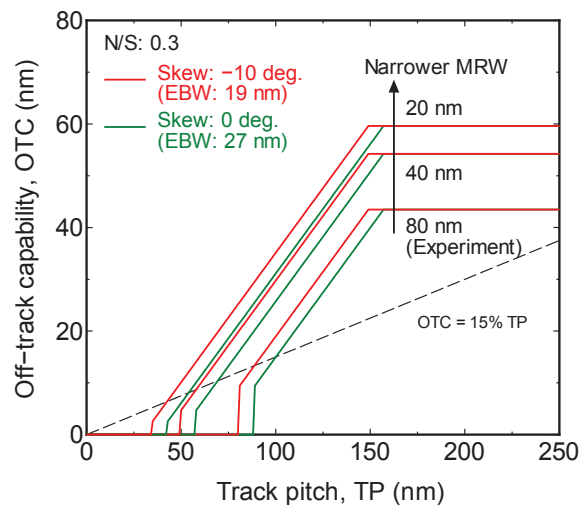


Fig. 6 Analytical 747 curves in the cases of MRW of 80, 40 20 nm.

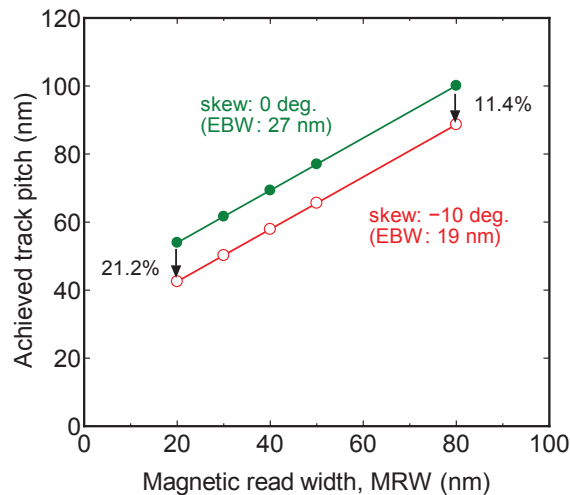


Fig. 7 Dependence of achieved track pitch on magnetic read width.

5. Conclusions

In order to achieve high track density in shingled writing, reducing erase band width in writing process performed by skewing head. Erase band width was experimentally decreased by 30% due to use of steeper head field gradient by skewing the head from 0 to -10 deg. Track pitch decrease of 7% was also accomplished in the measurement by the skew angle control only. This result indicates that reduction of erase band on one side is suitable for shingled writing and shingling direction is selectable so that we may minimize erase band width on the remained side. Additionally, a sophisticated ‘corner head’ that has an optimized shield structure will result in a narrow erase band width. In these experiments, an existing read head with wide magnetic read width was used. By narrowing the magnetic read width from 80 to 20 nm the improvement effect of achieved track pitch due to reduction of erase band width like this study will be enhanced from 11 to 21%.

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